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Horn Rapids Geophysical Survey, Stage 1 Preliminary Analysis Summary Report

Prepared for
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by Golder Associates Inc.

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1. INTRODUCTION

This summary report summarizes the results of the preliminary analysis for the geophysical survey at the Horn Rapids Landfill (HRL). The preliminary analysis consisted of:

- An evaluation of previous work by Pacific Northwest Laboratory (PNL) at the HRL;
- A review of similar surveys conducted elsewhere;
- Forward modeling of possible magnetometer responses to buried drums.

A previous geophysical survey at the Horn Rapids Landfill identified four main burial trenches that may contain up to 200 buried drums of carbon tetrachloride. Two main concerns were expressed by Department of Energy (DOE) and Environmental Protection Agency (EPA) at a meeting in January, 1991 as to (1) whether the trenches contain drums and (2) whether it is safe to drill in the burial trenches. As a result, a work plan for further detailed geophysical surveys of the main burial trenches was developed. It was agreed that anomalies corresponding to concentrations of 10 or more drums would be the focus of further investigation, and anomalies smaller than 10 drums would not be investigated further. The initial work plan specified that a preliminary pre-survey analysis of the magnetic response of a "threshold deposit" of 10 drums be evaluated prior to initiation of field work, including an evaluation of the effects of the distribution (i.e., stacked or scattered) of drums. Golder Associates Inc. were not involved in either the meeting or in developing the work plan.

The final task order plan for the geophysical surveys included two interim deliverables corresponding to the preliminary pre-survey analysis and a field survey summary prior to the final report. The following sections summarize the results of the preliminary analysis and recommendations for the field survey.

2. PRELIMINARY ANALYSIS

2.1 Evaluation of Previous Surveys

Previous geophysical surveys (EM, MAG, and GPR) were carried out by Pacific Northwest Laboratory (PNL) at the HRL using continuous recording instruments on a 100-foot line interval. The EM and MAG data were presented as a series of profiles corresponding to each trackline. Although this method of presentation is useful in observing the geophysical response along a trackline it is difficult to evaluate the aerial extent of anomalies without a map-view contour plot of the data. Plan view maps of "buried waste materials" are provided as rather indistinct hatch-marks on tracklines that showed anomalous responses, but the magnitude of the response is not presented. Positive magnetometer peaks of up to 4000 gammas were observed over portions of the trenches, which suggests that ferromagnetic materials do exist within the trenches. EM anomalies reach maximum relative amplitudes of over 2000 also suggesting highly conductive, metallic materials. It appears that only one component (quadrature) of the EM field was acquired during the survey. The EM-31 instrument used has the capability to acquire both quadrature and in-phase components of the EM field, and the in-phase component is more sensitive to metallic objects.

The GPR data was provided to us in the form of 3" by 5" photographic transparencies of processed GPR records. The data was acquired and stored using PNL file format that is now obsolete and cannot be interpreted by our computers. The photographic transparencies were of limited use because:

- There was no vertical depth/time scale;
- There was no indication of the antennae frequency used;
- The records had been processed to remove high amplitude reflections, and ground-surface reflections;
- The profiles were difficult to read because of their size.

GPR surveys were preformed by WHC at the 300-area site to investigate a known deposit of drums. Their survey was performed with a 300 MHz antennae, and the acquired data was apparently good with adequate signal response throughout the record. The drums were not identified from the GPR records because they were thought to be buried at a depth of less than 10-feet, and were actually buried at 12 feet. During the survey, the instrument was scaled to display only to a depth/time of 10 feet.

2.2 Review of Similar Surveys

2.2.1 Background

Geophysical surveys are common at landfills, hazardous waste sites, and for other shallow engineering studies where definition of shallow subsurface characteristics is required. Location of metallic objects is particularly suited to geophysical methods because of the high contrast in electrical properties. EM, magnetometer, and GPR techniques are routinely used for this purpose and it is well documented that they can, under many circumstances, identify trench boundaries, locate pipelines, and identify areas containing drums or other metallic debris. Qualitative evaluation of EM and magnetometer data with respect to metallic debris is relatively straightforward. In cases where the targets are well defined, and where excavation at anomalous areas is feasible and desirable, geophysical surveys are an excellent method for delineating potential problem areas. However, quantitative evaluation of EM and magnetometer data with respect to depth and exact location of metallic objects is not always simple, especially if there is abundant cultural or subsurface noise. The magnetic and electromagnetic response of highly conductive objects such as iron and steel is highly variable and influenced by a number of parameters that are not easily defined. Barrows (1988) discusses a number of potential complications to magnetometer responses in highly conductive environments such as landfills. Discrimination of drums from other iron or steel objects can therefore be very difficult except under highly controlled conditions.

Ground penetrating radar (GPR) is often very useful in discriminating targets. Depth, location, and extent of conductive targets can be determined from GPR data. Under ideal conditions, drums or pipes produce a characteristic parabolic or arcuate reflection pattern. Flat-lying reflectors that produce "ringing" or multiple reflections often correspond to crushed drums or plate-like steel objects.

2.2.2 Examples

An EM survey conducted at a landfill near Bellingham Washington (Ecology and Environment, 1988) indicated a conductive target that was thought to correspond to a concentration of buried drums. Excavation of the anomaly (Golder Associates, 1988) revealed four crushed drums and a number of steel objects, including automobile parts and a steel slab. Quantitative characterization of the geophysical response would likely not have predicted the actual contents revealed in the excavation. Integrated EM/magnetometer/GPR surveys at several sites in Western Washington (Williamson and Associates, 1991) were very successful in locating concentrations of buried drums, which were later excavated and removed. Similar integrated surveys (Williamson and Associates, 1991) at other sites indicated conductive targets that did not appear to be drums based on the GPR data. Excavation was required to verify the interpretation, but no drums were found. From these experiences it appears that an integrated survey approach including a detailed GPR survey is most likely to identify the nature of buried materials. However, excavation is the only means of positively identifying an anomaly detected with any geophysical survey.

2.3 Forward Modeling

2.3.1 Description and Scope

The model GMSYS, developed by Northwest Geophysical Associates, Inc. (1991), was used to produce theoretical magnetometer profiles over various configurations of drums within a trench. The software is simple and effective to use because the geologic model and magnetometer response are displayed simultaneously on the computer screen, providing immediate correlation of the model to the response. The model can be modified on the screen using a mouse and the magnetic response re-calculated to observe and compare a number of configurations or parameters. In addition to magnetic susceptibility parameters, the model can incorporate remnant magnetization (field strength, inclination, and declination), and survey azimuth. The model is 2 1/2-dimensional, which means that the 2-dimensional theoretical magnetometer profile is calculated using the third dimension (or strike length) of the geologic model. This is particularly important for modeling drums, which have a finite strike length. The calculations are based on an algorithm developed by Rasmussen and Pederson, 1979. The model uses Gaussian (cgs) units.

In developing the model, the following target types were defined:

- An "10-drum target" is a collection of 10 closely spaced or stacked drums or large metallic objects;
- A "single target" corresponds to a single drum or metallic object.
- A "dispersed target is a scattered collection of 10 drums or metallic objects;

The modeling attempted to address several response types. Each model was assigned an identifier for clarity, and these identifiers are referred to later in the text. The responses (with a model identifier) that were evaluated are summarized as follows:

- The ideal response of 10-drum target at various depths (Model A);
- The ideal response of a single target at various depths (Model B);
- The ideal response of a collection of 10 single targets or metallic objects (Model C);
- The effect of non-ideal situations including: noise created by smaller discrete objects above a 10-drum target, and bulk magnetic susceptibility of the burial trench (Model D). Remnant magnetization was not evaluated for the preliminary analysis.

9 2 1 2 5 4 2 3 2 2 9

2.3.2 Model Parameters

There are a number of parameters to consider when attempting to model metallic objects in the subsurface. Constant parameters used throughout the modeling exercise are summarized as follows:

Magnetic field strength (H)	56,000 gammas
Magnetic field inclination (I)	70 degrees
Magnetic field declination (D)	19 degrees
Magnetometer station spacing (X)	10 feet (3.3 m)
Magnetometer station elevation (h)	6.5 feet (2 m)
Single Drum Target Dimensions (Length, Diameter (width, height)	5, 2.5 feet
10-drum target dimensions (Length, Width, Height)	12.5, 10, 2.5 feet

Calculated, estimated, or varied parameters included:

- Magnetic susceptibility (k)
- Target strike length (+Y,-Y)
- Target depth (Z)

A range of magnetic susceptibility (k) was estimated for the modeling exercise based on theoretical and reported values. These values are summarized below:

k_{eff} (cgs)	Reference
0.5	Relative volume calculation (EG&G, 1988)
0.2	Demagnetization Factor (Grant and West, 1965)
0.1	Reported value (Barrows, 1988; Gilkeson et al., 1986)

Other parameters were assigned as follows:

Target strike length (+Y,-Y)	+Y : 0 - 5 feet -Y : 0 - 5 feet
Target Depth (Z)	5, 10, 20 feet

2.3.3 Model Results

Typical output from the GMSYS program is shown on Figure 1. Since the objective of the modeling was to identify ranges of potential responses of targets, and because a number of model runs were generated, the modeling results are presented as tables, corresponding to the specific model identifiers shown above.

The results of model A, a 10-drum target, are presented in Table 1. This table shows the effect of burial depth and magnetic susceptibility with respect to the amplitude and wavelength of an anomaly created by a 10-drum target.

TABLE 1

THEORETICAL MAGNETOMETER RESPONSE TO 10-DRUM TARGETS (MODEL A)

Target Depth (ft)	keff (cgs)		
	0.1	0.2	0.5
5	(1000, 40)	(1700, 50)	(4000, 60)
10	(400, 40)	(700, 50)	(2000, 60)
20	(100, 40)	(300, 50)	(600, 60)

Note: Tables show magnetometer response (A, W) in terms of amplitude (A, in gammas) and wavelength (W, in feet) of a theoretical magnetometer anomaly.

The results of model B, a single-drum target, are presented in Table 2. This table shows the effect of burial depth and magnetic susceptibility with respect to the amplitude and wavelength of an anomaly created by a single-drum target.

9 2 1 2 3 2 2 7 2 2 3 1

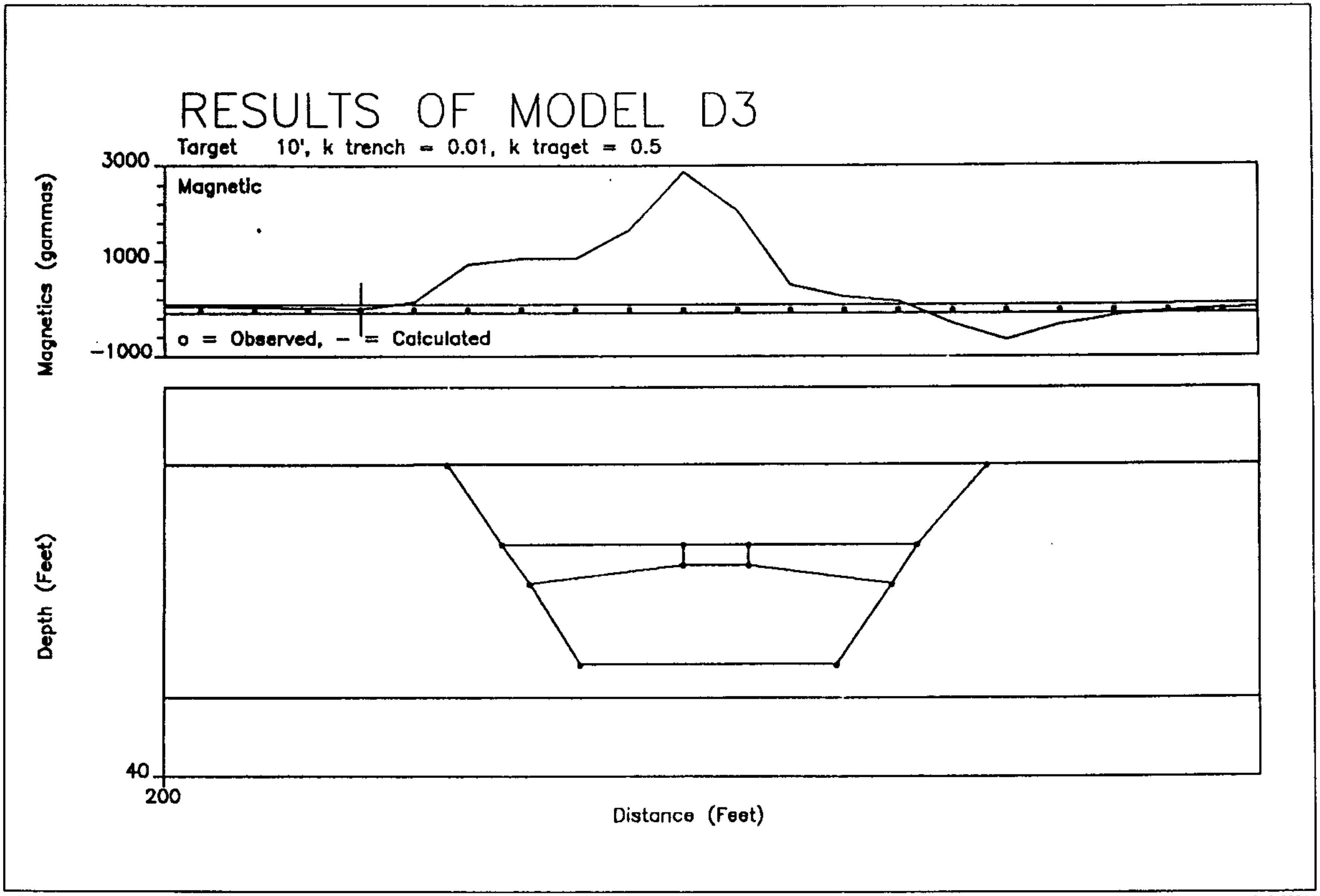

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Figure 1. Typical Output Display of Magnetometer Model

TABLE 2

THEORETICAL MAGNETOMETER RESPONSE TO 1 DRUM TARGETS (MODEL B)

Target Depth (ft)	keff (cgs)		
	0.1	0.2	0.5
5	(120, 40)	(230, 40)	(550, 40)
10	(50, 40)	(100, 40)	(250, 40)
20	(15, 40)	(35, 40)	(80, 40)

Note: Tables show magnetometer response (A, W) in terms of amplitude (A, in gammas) and wavelength (W, in feet) of a theoretical magnetometer anomaly.

Comparison of these two tables shows that the amplitude of a 10-drum target may range from 100 to 4,000 gammas, while its wavelength may vary between 40 and 60 feet. A single drum target has a range of amplitudes of 15 to 120 gammas, with high amplitudes corresponding to shallow burial depths. Comparison of these model results suggests that short wavelength anomalies (40 feet or less) do not likely correspond to drum targets and that low amplitude anomalies, (300 gammas or less) do not likely correspond to collections of 10 drums.

The results of model C, a collection of 10 single drum targets, are presented in Table 3. This table shows the anomaly produced by a collection of ten 1-drum targets spaced at 5-foot and 10-foot intervals, with a magnetic susceptibility of 0.2 and a burial depth of 10 feet. Other burial depths were not evaluated for the preliminary analysis. The effect of spacing the drums apart is to increase the wavelength and decrease the amplitude of the anomaly. Compared to an ideal 10-drum target buried at 10 feet, the amplitude of the anomaly is decreased by 15 percent for a 5-foot target spacing and by 66 percent for a 10-foot target spacing. The wavelength of the anomaly increases, but the anomaly does not separate into discrete peaks caused by the individual targets. Therefore, the model predicts that targets spaced by 10 feet or less will still appear as singular anomalies using grid spacing of 10 feet.

TABLE 3

THEORETICAL MAGNETOMETER RESPONSE TO TEN 1-DRUM TARGETS AT DIFFERENT SPACINGS (MODEL C)

Target Depth (ft) (K_{eff} = 0.2 cgs)	Target Spacing (ft)	
	5 ft	10 ft
10	(600, 80)	(250, 100)

Note: Tables show magnetometer response (A, W) in terms of amplitude (A, in gammas) and wavelength (W, in feet) of a theoretical magnetometer anomaly.

It is likely that in performing and interpreting the survey that actual conditions at the HRL will not correspond to the ideal conditions evaluated in the model. The trenches have received considerable amounts of construction debris, some of which is visible at the ground surface. This debris will likely contribute a significant amount of noise to the survey which must be carefully evaluated in determining the location of targets. It is beyond the scope of a preliminary modeling exercise to evaluate numerous configurations of targets and other debris within the trench. However, two simple configurations were evaluated with the model. The effect of placing two small objects above a larger 10-drum target is shown on Table 4. The effect of the surface objects is to increase the amplitude of the anomaly, but the wavelength remains similar.

TABLE 4

THEORETICAL MAGNETOMETER RESPONSE UNDER NON-IDEAL CONDITIONS

Target Depth	Near Surface Objects k = 0.5 Target k = 0.2 Surface Object	Trench Susceptibility k = 0.5 Target k = 0.01 Trench		Trench Susceptibility k = 0.5 Target k = 0.05 Trench	
		Trench Amplitude	Target Amplitude	Trench Amplitude	Target Amplitude
5	-	-	-	-	-
10	(950, 50)	1000	3000	5000	6000
20	(500, 50)	-	-	-	-

The second configuration evaluated the effect of bulk trench susceptibility. There is the possibility that enough ferromagnetic material is distributed throughout the trenches, such that the trench will act as a large target and mask the response of other targets (i.e. drums) within the trench. Barrows (1991) suggests that a bulk volume of 1 percent ferromagnetic material disseminated throughout a trench is sufficient to produce saturation susceptibility, such that the trench itself may mask all other magnetic targets. The effect of a small amount of metal disseminated throughout the trench was evaluated with GMSYS by applying a susceptibility of 0.01 (50 times less than the target), but a strike length of 100 feet (50 times greater than the target). The resulting anomaly (see Figure 1) shows high total field gradients both at the edge of the trench and also near the target. The amplitude of the anomaly increases at the edge of the trench and increases further over the target. Assigning a trench susceptibility of 0.05 cgs increases the amplitude of the responses significantly; and masks the response of the target. Table 4 shows the amplitudes of the anomalies produced over the trench and over the target.

3. SUMMARY AND CONCLUSIONS

The results of the preliminary analysis are summarized as follows:

- Previous surveys at the HRL suggest that buried metallic debris exists within the burial trenches. However, the reconnaissance nature of the survey (100-foot line spacing) limited the ability of the survey to delineate areas likely to contain discrete metallic objects. The previous survey did not collect EM data at long coil spacing (EM-34 instrument) which limits the depth of penetration of the EM survey data to about 18 feet. The previous survey did not collect EM in-phase measurements, and total magnetic field gradient measurements, which would be useful in detecting metallic objects.

- Integrated surveys consisting of EM, magnetometer and GPR surveys are effective in delineating areas containing metallic objects, and often in characterizing the types of objects buried in the subsurface. However, the HRL may contain abundant metallic debris which may create numerous geophysical targets which may or may not correspond to buried drums.

- Forward modeling of potential magnetometer responses suggests that a collection of 10 drums will have an anomaly wavelength of between 40 and 80 feet, depending on whether the drums are closely spaced or scattered. The amplitude of the anomaly may range from less than 100 gammas to over 2000 gammas depending on the depth of burial and the effective susceptibility of the drums. Total magnetic field gradient will produce smaller wavelength anomalies which would be useful in providing a more accurate target location and for discriminating near surface noise from deeper target responses. Electromagnetic and GPR responses were not quantitatively modeled as part of the preliminary evaluation.

- The range of magnetometer responses indicated from the model are a preliminary estimate only, and actual field responses are likely to differ from the model responses. GPR data should provide suitable data for characterizing targets identified with the EM and magnetometer. If the GPR is not successful in characterizing the targets, a 10-foot grid spacing will be useful for additional processing of the EM/magnetometer data.

4. RECOMMENDATIONS

Based on the results of the preliminary analysis, we will carry out the geophysical survey as follows:

- Perform EM and MAG surveys at a 10-foot grid spacing;

- Perform the EM survey in accordance with Golder Associates Technical Procedures and insure that both quadrature and in-phase components of the EM field are recorded and that instrument is oriented both north-south and east-west at each station;

- Perform the MAG survey in accordance with Golder Associates Technical Procedures and insure that both total field and total field vertical gradient data are acquired at each station;

- Contour EM and magnetometer data in the field using a simple contouring program such as SURFER to identify "hot spots". These hot-spots will be surveyed with the GPR instrument immediately after the EM/MAG data is processed. If numerous "hot spots" are identified, anomalies of lower amplitude or wavelength will not be investigated with the GPR. For the purposes of the field survey, a threshold amplitude of 300 gammas, and a threshold wavelength of 40 feet will be established. Anomalies less that 300 gammas and 40 foot dimensions will not be surveyed with the GPR unless GPR data quality is good and there is sufficient time.

- Anomalous areas delineated with the EM and MAG survey will be surveyed with the GPR at 5 foot interval, recording both a paper record and digital tape. A field calibration exercise will be carried out using a 500 MHz, 300 MHz and 120 MHz antennae to determine the optimum antennae for depth penetration and horizontal resolution for the soil conditions at the HRL. Based on past WHC experience, a 300 MHz antennae should be adequate. Parabolic or arcuate reflective patterns will be given a high probability of being drums. Flatlying reflectors that produce multiple reflections will be assigned a moderate probability of being drums. A minimum GPR target area of 25 x 25 feet will be established as a potential "10-drum" target.

- If there are numerous or large target areas that cannot be discriminated as to their nature or contents using the GPR data, two steps may be taken:

   1. Additional data collection using an EM-34 electromagnetic instrument at 10 m and 20 m coil separations may be used to characterize the vertical extent of large targets and of the trench itself. Larger coil separations may reduce the effects of near surface noise which may influence the shallow EM-31 data. If field evaluation suggests that EM-34 data is desirable, an EM-34 instrument should be mobilized to the site.

2. Further processing of the EM and magnetometer data may also be necessary to filter the data. GEOSOFT software may be used to apply modeled magnetometer anomalies to the field data as a filter. High frequency or low amplitude anomalies will therefore be filtered out of the data to emphasize anomalies that correspond (based on the model response) to concentrations of 10 drums. Other filters may also be designed and applied to the EM and magnetometer data based on the dynamic range and frequency characteristics of the data.

Further characterization of large or numerous targets identified in the field was not specified in the initial task order plan (GAI, 1991). It is our intent to fully characterize anomalies using the field techniques specified in the task order. We anticipate that additional survey time and costs using the EM-34 (if necessary) will not exceed the initial schedule and budget. However, additional data processing is beyond the initial task order plan, and, if required, would require a change order. We will defer final decision to proceed with more detailed data processing and analysis to WHC.

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